Imaging the Heart of a Cell: Hydrogen Fuel Cells and Nanomedicine

NIST researchers conceived and designed an imaging technology that could break the neutron detector resolution barrier. Until recently, there was no instrument that provided the ability to observe the chemical actions operating in a fuel cell or across a single biological cell subjected to certain drug treatments. X-ray techniques were ineffective or destructive. Neutron radiation is gentle enough; however existing neutron detectors could not resolve features much finer than 20 micrometers. Exploratory research on the NIST design suggests that neutron-imaging resolution could be improved by two orders of magnitude – achieving a useful resolution that can address crucial dynamical aspects of both biological cells and fuel cells.

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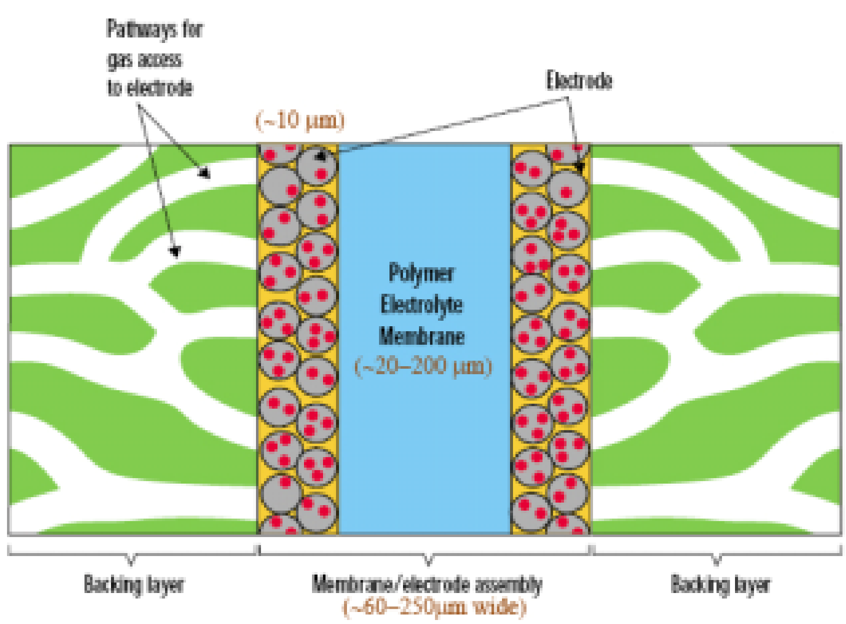
Hydrogen fuel cell development plays an important role in the national effort to establish a viable hydrogen economy. Currently scientists are striving to improve fuel cell efficiency and longevity. Their progress is impeded by the inability to map the flow characteristics of hydrogen species across the proton exchange membrane (PEM). This thin membrane, only 10 to 200 micrometers thick, divides the cell but more importantly serves as the conduit for charge carriers, hydrogen ions, and associated catalytic impurities that are embedded in the PEM over time.

The problem has been "seeing" through the massive mechanical structure that constitutes the cell, yet resolving the submicrometer distribution of hydrogen as it flows across the membrane. Neutron probes have recently been used to penetrate through a working fuel cell and measure the quantity and distribution of hydrogen compounds *in situ*. However, existing neutron image resolution is limited to 20 to 125 micrometers. The membrane itself is about this thickness. To address the problem, we have conceived and designed an imaging technology that breaks the current neutron detector resolution barrier.

The innovative detector uses specially designed coincident, high-speed, time-of-flight sensors developed for planetary space probes. Intense neutron beams from the NIST Center for Neutron Research (NCNR) shine through the operating fuel cell in much the same fashion as does an x-ray at the doctor's office, however the neutrons shine continuously. The image of the hydrogen flow is projected upon the detector that is carefully aligned beneath the cell. Time- resolved images might be obtained if the neutron fluence is adequate. Multidimensional images can be extracted too.

Initial calculations show that theoretical resolution of the detector is better than 100 nanometers. Biological cell imagining then becomes a possibility with this resolution. Furthermore, cold neutrons are penetrating and have an associated energy of milli-electron volts, a very cold breeze of particles that mostly pass through the sample. Cancer drugs containing boron-, gold-, or gadolinium-loaded nanotubes or liposomes would be readily visible in the cell. The detector would reveal the amount and the location of these compounds and verify if indeed the drugs were reaching the cell nucleus as thought. All this valuable information provides interpretive diagnostics to direct medical research.

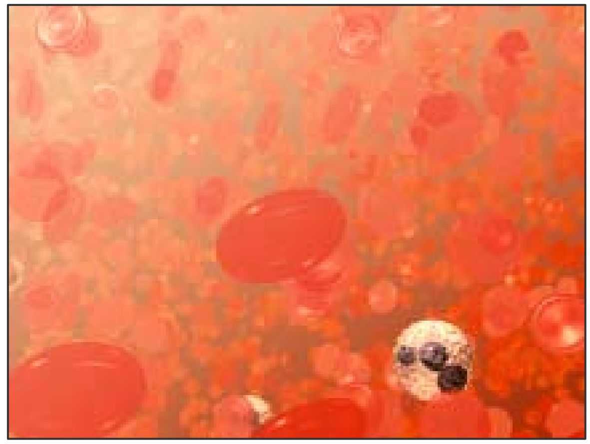
The detector design was funded under a CSTL exploratory program. The NIST's Physics Laboratory is providing funding to build a prototype detector as part of this collaborative effort.



Enlarged cross-section of a membrane/electrode assembly showing structural details.

Impact: Two of the largest burdens on the US economy are medical and energy costs. This instrument has the potential to advance research in both of these major areas. By partnering with industry and academia, new insight can be made into the chemical dynamics of cancer drugs in cells and hydrogen flow in PEMs – all at the nanoscale.

Future Plans: A prototype instrument will be assembled to conduct the proof of concept test. If successful, then plans are to construct a fully functioning device including environment controls for biological specimens and engineering to image working hydrogen fuel cells.



Source: National Cancer Institute, Donald Bliss (Artist)